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NEUTRINO OSCILLATIONS WITH BEAMS FROM AGN'S AND GRB'S*

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ABSTRACT

I discuss how a 1 KM3 neutrino detector can be used to study ν_τ oscillations at PeV energies with neutrinos from AGN's and to study neutrinos from GRB's.

1. Introduction

I would like to discuss two topics: (i) the observation of $\tau's$ from $\nu_\tau' s$ produced in oscillations of $\nu_\mu' s$ from Active Galactic Nuclei with energies of a few PeV and (ii) possible observation of $\nu_\mu' s$ and $\nu_e' s$ from Gamma Ray Bursters with energies ranging from MeV to TeV. Details and a complete set of references are to be found in References [1] and [2].

The main assumption I make is that a next generation DUMAND-like water Cerenkov under-H_2O array of dimensions of order of $1km^3$ will be available at some future date to detect neutrino interactions.

2. Neutrinos from Active Galactic Nuclei

For AGN's the expectations are that they emit high energy $\nu's$; the total flux overtakes atmospheric ν-flux by $E_\nu \sim 0(TeV)$ and the most likely flavor mix is $\nu_\mu : \nu_e : \nu_\tau \approx 2 : 1 : 0$. This is my second major assumption.

2.1. ν_τ Signature

For a ν_τ of energy above 2 PeV there is a characteristic "double bang" signature. When ν_τ interacts via charged current there is a hadronic shower (of energy E_1) with about 10^{11} photons emitted; then the τ travels about 90m (for $E_\tau \sim 1.8PeV$) and when it decays (either to e's or hadrons with 80 % probability) there is again a cascade (of energy E_2) with 2.10^{11} photons emitted in Cerenkov light. The τ track is minimum ionising and may emit $10^6 - 10^7$ photons; even if it is not resolvable, one can connect the two showers by speed of light and reconstruct the event.

The backgrounds (after appropriate cuts) are very small. Hence such "double bang" events represent either $\nu_\mu \to \nu_e$ (or $\nu_e \to \nu_\tau$) oscillations or ν_τ-emission at the

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source and in any case are extremely interesting. For signal events due to ν_τ, one expects $E_2/E_1 > 2$ on the average, and hence a cut of $E_2/E_1 > 1$ removes many backgrounds; another cut on the distance D between the two bangs of $D > 50m$ eliminates most of the punch-thru backgrounds.

Extra bonuses from observing these double bang events are: (i) use of the zenith angle distribution to measure σ_ν via attenuation and (ii) use of the enormous light collection and good timing to get good vertex resolution and determine ν_τ direction to within one degree.

2.2. Expected Flavor Mixes

Most models of ν-emission in AGN's correspond to tenuous beam dumps with little absorption and $\nu's$ come from π (and K) decay. Frequently $\gamma p \to \Delta$ is a dominant process. In these scenarios we expect at production

$$\nu_\mu : \ \nu_e : \nu_\tau \approx 2 : 1 : 0$$

For example, in the Protheroe-Szabo model, they find $\nu_\mu : \nu_e \approx 1.75 : 1$ and 10% of $\nu's$ come from pp interactions. Some fraction of pp collisions will contribute to prompt $\nu's$ (including $\nu_\tau's$) via production of c and b. In the prompt $\nu's$ the flavor mix is

$$\nu_\mu : \nu_e : \nu_\tau = 1 : 1 : p$$

where p can be crudely estimated to be about 0.07 to 0.1. Since the prompt $\nu's$ themselves are expected to be only 10% of total the modified flavor mix is

$$\nu_\mu : \nu_e : \nu_\tau \approx 1 : 0.6 : 0.01$$

and contains less than 1% of $\nu_\tau's$.

2.3. Rates

To estimate event rates we make the following assumptions: (i) assume the fluxes of Protheroe-Szabo model (ii) integrate over all AGN's (iii) assume an initial flavor mix of $\nu_\mu : \nu_e \nu_\tau \approx 2 : 1 : 0$ and $\nu_\mu \to \nu_\tau$ conversion such that on arrival the flavor mix is $\nu_\mu : \nu_e : \nu_\tau = 1 : 1 : 1$ (iv) a 1km^3 water $\hat{c}$ detector with 100 % detection efficiency. Then we expect 1000 ν_τ "double bang" events and about 1800 showering events ($\nu_e CC$ and ν_α NC) per year.

2.4. Oscillations

The neutrino flavor mix can be easily determined from the event classification of the data. The double bang events determine $\nu_\tau + \bar{\nu}_\tau$ flux; the upcoming muons

determine $\nu_\mu + \bar{\nu}_\mu$ flux; the cascade events (single bang) determine a combination of $(\nu_e + \bar{\nu}_e), (\nu_\mu + \bar{\nu}_\mu)$ and $(\nu_\tau + \bar{\nu}_\tau)$ fluxes; and Glashow Resonance (W) events determine $\bar{\nu}_e$ flux (at $E_\nu = 6.4 PeV$).

The sensitivity to oscillation parameters depends on several factors. If individual AGN's can be seen in $\nu_\tau' s$ (say to 100 mpc) then δm^2 upto $\geq 10^{-16} ev^2$ can be probed. The mixing angle sensitivity is limited by $\sin^2 2\theta > 0.01$ due to some initial ν_τ present and in practice probably closer to 0.05 to 0.1.

To proceed further let us assume: (i) initial fluxes are $\nu_\mu : \nu_e : \nu_\tau \approx 2 : 1 : 0$; (ii) $\# \ \nu = \# \ \bar{\nu}$ (although this is not essential); (iii) all $\delta m^2 >> 10^{-16} eV^2$, i.e. $< sin^2 \ (\delta m^2 L/4E) > \approx 1/2$; (iv) matter effects negligible at production (e.g. $N_{e-} = N_{e+}$) and no significant matter effects en-route (this is valid for δm^2 of current interest $\sim 10^{-2} - 10^{-6} ev^2$); (v) atmospheric ν-anomaly caused by $\nu_\mu - \nu_\tau$ oscillations with $\delta m^2 \sim 10^{-2} ev^2$ and $\sin^2 2\theta \geq 0.6$. In this case we expect $\nu_\mu : \nu_e : \nu_\tau \approx 1 : 1 : 1$ at earth. If on the other hand, the atmospheric anomaly is due to $\nu_\mu - \nu_e$ mixing the flavor mix on arrival is 1:1:0. These two cases are easy to distinguish with the annual rate of double bang events varying from 1000 to zero. We have also considered 3 neutrino mixing with solar neutrinos accounted for by either MSW or LWO oscillations and found a large ν_τ flux is always found; and the various solutions can be distinguished by the different $\nu_\mu \nu_e, \nu_\tau$ fluxes observed. As two limiting cases of interest: (i) a pure prompt flux 1:1:01 becomes 1:1.6 :0.7 with $\nu_\mu \rightarrow \nu_\tau$ conversion and is very distinct and (ii) an initial universal flux 1:1:1 remains universal!

2.5. Backgrounds and Summary

We have considered several possible sources of backgrounds which fake double bang signatures. The most serious appears to be a $\nu_\mu \rightarrow \mu$ charged current event where the μ travels about 100 m without much radiation and then deposits the bulk of its energy in a catastrophic bremstrahlung. This would have all the characteristics of a genuine ν_τ event. We estimate the fraction of such events to be about $(m_e/m_\mu)^2 (100m/R_\mu)(\Delta E/E) \sim 3.10^{-3}$ and seems reassuringly small.

At the hadronic vertex, the sources of background are: (i) $\nu_e + N \rightarrow e + D_s$ produced diffractively with $D_s \rightarrow \tau\nu$; and E_2/E_1 can be of 0(1) to fake the ν_τ signal provided D_s decays quickly. The rate is expected to be of order 3.10^{-4} of cc events; (ii) $\nu_\alpha + N \rightarrow \nu_\alpha + D_s/B$ again with D_s or B decaying into τ within 10m and τ traveling 100 m. In these events we expect $E_2/E_1 < 1$ and again the rate is small of order $\sim 10^{-3}$. Other backgrounds such as coincident downgoing $\mu' s$ showering is expected to be small. Hence, that after the cuts such as $E_2/E_1 > 1$ and $D > 50m$, the backgrounds are rather small.

We conclude that given AGN ν-sources, it is possible to see $\nu_\tau \rightarrow \tau$ events in a 1 km3 array unambigously. One can measure ν_τ mixing angles $(sin^2 2\theta > 0.1)$ and $\delta m^2 (> 10^{-16} eV^2)$ and/or determine the presence of ν_τ in the initial beam. If ν_τ

mixing were known from terrestrial experiments one would learn about the nature of AGN ν-emission processes. *We feel that this already justifies the construction and deployment of a $1km^3$ array.*

3. Gamma Ray Bursters

The gamma ray bursters remain rather enigmatic; but the current indications are that they are probably at cosmological distances with very high luminosities. Their luminosities seem to be in a narrow range and they may be almost standard candles. The photon energies occasionally reach GeV and the spectrum may be power law ($\sim 1/E^2$). Perhaps the gamma rays come from π^0 decay, in which case there should be $\nu_\mu's$ from $\pi^\pm$ decay. In models like those of Paczynski-Xu this is indeed the case. We assume this is true and take as nominal values $\phi_\gamma \sim 1 per cm^2$ at 1 MeV, $\phi_\gamma \sim 1/E^2$ and let $\phi_\nu \sim \eta\phi_\gamma$. In some models η can be much larger than one. The flavor mix should be $\nu_\mu : \nu_e \sim 2 : 1$ as in atmospheric neutrinos and modified by osscillations. In principle one can be sensitive to δm^2 to $10^{-19} eV^2$. Many other neutrino properties can be probed to new levels. An exciting new twist is the ability to measure Hubble red shift in neutrinos, providing a first non-electromagnetic test of the expansion.

Typical rates in neutrino telescopes such as DUMAND, AMANDA etc. are $\sim 1.5.10^{-2}\eta$ correlated $\mu's$ per year for E_{th} of 20 GeV. For the 1km3 detector the number is 1.5η correlated $\mu's$ per year and $10^{-2}\eta$ $\mu's$ per burst. Considering η can be as high as 100 these are non-negligible. For the brightest 0.1% of GRB's, one may witness a burst of $100\mu's$ once a year.

Any detection of GRB'S in neutrinos would be fantastic. But to make this happen, we need ν-Telescopes with largest possible area (for high energies), volume (for low energies) and lowest possible threshold (to increase rate as well as to do flavor analysis etc).

I believe we have given a strong rationale for building a $1km^3$ neutrino detector and shown that there is very exciting physics and astrophysics out there waiting to be discovered.

4. Acknowledgments

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5. References

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